

**NAVAL POSTGRADUATE SCHOOL**  
**Monterey, California**



19980526 037

**THESIS**

**A MONTHLY SORTIE SCHEDULING  
MODEL FOR IMPROVED EA-6B PROWLER COMBAT  
READINESS**

by

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March 1998

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**DTIC QUALITY INSPECTED 2**

<b>REPORT DOCUMENTATION PAGE</b>			Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.				
1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE March 1998		3. REPORT TYPE AND DATES COVERED Master's Thesis
4. TITLE AND SUBTITLE A Monthly Sortie Scheduling Model For Improved EA-6B Prowler Combat Readiness			5. FUNDING NUMBERS	
6. AUTHOR(S) Scott H. Swords				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000			8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) COMVAQWINGPAC, NAS Whidbey Island, 3730 N. Chas. Porter Ave., Oak Harbor, WA 98278-7500			10. SPONSORING / MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.				
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.			12b. DISTRIBUTION CODE	
13. ABSTRACT (maximum 200 words). EA-6B Prowler crews conduct a variety of missions and are required to fly and train with sufficient regularity to maintain combat proficiency. These crews maintain this proficiency by completing regularly scheduled training qualifications. Squadrons determine their readiness level based on the percentage completion of these qualifications. Squadrons currently use an <i>ad hoc</i> method for scheduling training. This thesis develops a mixed integer program to plan monthly sorties, as a decision aid for squadron operations officers. The goal is to maximize squadron combat readiness by minimizing the number of aviators not fully combat-ready, subject to the number of flights available. The model is programmed in the GAMS language and uses a spreadsheet interface for both input and output. It is typically solved in 10 minutes on a Pentium 120 MHz PC with the OSL solver. The output is a matrix of pilots to flight assignments and aircrew to flight and seat assignments. This approach immediately yields a 10% improvement in average monthly readiness as compared to the <i>ad hoc</i> method and should be implemented as a methodology for scheduling monthly sorties.				
14. SUBJECT TERMS COMNAVAIRPACINST 3500.67C, EA-6B Prowler, Readiness, Scheduling, Training			15. NUMBER OF PAGES 79	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT UL	

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)  
Prescribed by ANSI Std. Z39-18 298-102



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A MONTHLY SORTIE SCHEDULING  
MODEL FOR IMPROVED EA-6B PROWLER COMBAT READINESS

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Submitted in partial fulfillment of the  
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL  
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## ABSTRACT

EA-6B Prowler crews conduct a variety of missions and are required to fly and train with sufficient regularity to maintain combat proficiency. These crews maintain this proficiency by completing regularly scheduled training qualifications. Squadrons determine their readiness level based on the percentage completion of these qualifications. Squadrons currently use an *ad hoc* method for scheduling training. This thesis develops a mixed integer program to plan monthly sorties, as a decision aid for squadron operations officers. The goal is to maximize squadron combat readiness by minimizing the number of aviators not fully combat-ready, subject to the number of flights available. The model is programmed in the GAMS language and uses a spreadsheet interface for both input and output. It is typically solved in 10 minutes on a Pentium 120 MHz PC with the OSL solver. The output is a matrix of pilots to flight assignments and aircrew to flight and seat assignments. This approach immediately yields a 10% improvement in average monthly readiness as compared to the *ad hoc* method and should be implemented as a methodology for scheduling monthly sorties.

## THESIS DISCLAIMER

The reader is cautioned that computer programs developed in this research may not have been exercised for all cases of interest. While effort has been made, within the time available, to ensure that the programs are free of computational and logic errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

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## LIST OF ABBREVIATIONS AND ACRONYMS

AAW	Air to Air Warfare (Event Code)
AAW	Anti-Air Warfare (PMAs)
ACT	Air Combat Training
ASU	Anti-Surface Warfare
CATM	Captive Air Training Missile
CCC	Command, Control and Communication
CNAL	Commander, Naval Air Forces Atlantic
CNAP	Commander, Naval Air Forces Pacific
COMNAVAIRPAC	Commander, Naval Air Forces Pacific
COMVAQWINGPAC	Commander, Electronic Attack Wing Pacific
CQ	Carrier Qualification
C2W	Command and Control Warfare
DDI	Digital Display Indicator
ESM	Electric Surveillance Measures
ECM	Electronic Counter-Measures
ECMO	Electronic Counter-Measures Officer
EWA	Electronic Warfare and Attack
FAM	Familiarization
FCLP	Field Carrier Landing Practice
GAMS	General Algebraic Modeling System
HARM	High Speed Anti-Radiation Missile
INT	Interdiction

LP	Linear Program
MIP	Mixed Integer Program
MOB	Mobility
NATOPS	Naval Air Training and Operating Procedures Standardization
NAV	Navigation
OSL	Optimization Subroutine Library
PC	Personal Computer
PMA	Primary Mission Area
QUAL	Qualification
SORTS	Status Of Resources and Training System
STK	Strike
STW	Strike Warfare
TRAX	Training and Readiness Automated Matrix
USMC	United States Marine Corps
WAG	Weapons Air to Ground

## EXECUTIVE SUMMARY

The world's premiere tactical electronic warfare airplane is the U.S. Navy's EA-6B Prowler. The primary mission of the aircraft is degradation of enemy electronic activity and obtaining electronic intelligence within a combat area. Prowler crews accomplish this through a variety of tactical missions, requiring them to fly and train with sufficient regularity to maintain combat proficiency.

Prowler crews maintain this proficiency by completing a series of qualifications at regularly scheduled intervals. A squadron determines its readiness level based on the percentage completion of these qualifications. These qualifications encompass seven warfare areas a unit must be fully capable of performing to carry out assigned tasks. Currently squadrons use an *ad hoc* method for scheduling pilots and aircrew to their qualifications.

This thesis develops a mixed integer program to plan monthly sorties and qualifications. The model is designed as a decision aid for squadron operations officers. The goal is to maximize squadron combat readiness by minimizing the number of aviators not fully combat-ready, subject to the number of flights available. The model is programmed

in the GAMS language and uses a spreadsheet interface for both input and output. It is typically solved in 10 minutes on a Pentium 120 MHz PC with the OSL solver.

The output is a matrix of pilots to flight assignments and aircrew to flight and seat assignments. The output allows the decision maker to generate flight crews for each flight assignment based on squadron Standard Operating Procedures and their best judgement.

This approach yields a 10% improvement in readiness for a given month as compared to the *ad hoc* method. It also yields a cumulative effect where the increased readiness in prior months leads to an increase in readiness in following months.

## ACKNOWLEDGEMENTS

The author would like to thank the following persons for their contributions in the preparation of this thesis:

Dr. John F. Raffensperger for his direction, support, and patience.

Professor Rick Rosenthal for his guidance in getting this project started.

LCDR William Dannella, LCDR Brad Russell, and LT Brian Souchet for their assistance in interpreting the CNAP/CNAL instructions and for providing the flight data.

Mom and Dad for lessons too numerous to list.

Kristi and Lauren for their love, encouragement, and patience. This thesis is as much theirs as it is mine.



## I. INTRODUCTION

The world's premiere tactical electronic warfare airplane is the U. S. Navy's EA-6B Prowler. The primary mission of the aircraft is support of strike aircraft and ground troops by degrading enemy electronic activity and obtaining tactical electronic intelligence within a combat area [Ref 1:p. I-1-1]. This is accomplished through a variety of tactical missions ranging from Suppression of Enemy Air Defenses, to jamming hostile radar, to Electronic Surveillance Missions. This variety of missions require pilots and Electronic Counter-Measures Officers (ECMOs<sup>1</sup>) to fly and train in the EA-6B with sufficient regularity to maintain proficiency in these missions.

Maintaining this proficiency involves completing a series of designated training events. These events, known as qualifications, or *quals*, must be repeated at regularly scheduled intervals. Squadrons determine their readiness level based on the percentage completion of these qualifications. Squadrons currently use an *ad hoc* method for assigning pilots and ECMOs to their designated training events. This results in choosing aviators whose

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<sup>1</sup> A comprehensive list of acronyms and their meanings is available on page xi.

qualifications expire the soonest, with no regard for the actual value of the training event. This thesis develops a mixed integer programming model to help the squadron operations officer maximize squadron readiness by assigning aviators to the best mix of training events, while not exceeding the number of flights available to be scheduled.

#### **A. READINESS**

Prowler and all other Naval Aviation Squadrons are required to report combat readiness status on a monthly basis to their respective fleet commanders. Every squadron publishes two messages known as the Status of Resources and Training System (SORTS) report and the Monthly Training Report. The squadrons send these reports to the Commander Naval Air Forces Pacific (CNAP) or Commander Naval Air Forces Atlantic (CNAL). CNAP and CNAL have jointly set forth comprehensive readiness, reporting, and training standards in an instruction that covers all aircraft communities. [Ref.2]

The purpose of this instruction is to promulgate specific aircraft training matrices for flight crews of the Naval Air Force, U. S. Pacific Fleet and U. S. Atlantic Fleet. [Ref. 2:p. 2] The instruction states:

Readiness is the assessed capability of a unit to perform its assigned mission. Readiness is assessed through

a variety of factors including personnel, supply, equipment, and training. The tool that best assesses readiness is the SORTS report. This instruction is for the use of commanders and commanding officers to achieve the highest level of aircrew training feasible and assessing and accurately reporting that level of aircrew training. Aircrew training is then an input into the assessed level of readiness of a unit.[Ref 2, Encl.(1):p. 1]

The SORTS message provides the chain of command with essential information concerning squadron combat readiness and mission capability [Ref 2, Encl.(20):p. 1]. The SORTS message reports three types of ratings: the M, C, and overall C-rating. These ratings are reported on a scale from one to four with one indicating the highest and four the lowest.

The *M-rating* refers to mission area readiness. For Prowlers, the M-rating covers seven Primary Mission Areas (PMAs). These are warfare areas a unit must be fully capable of performing to carry out assigned tasks [Ref 3:p. 6]. For each of the PMAs, the M-rating describes the squadron's mission capability in terms of four resource areas: personnel, supplies on hand, equipment, and training. The M-rating is the highest number across the four resource areas indicating the lowest mission resource area for that PMA. The relationship between the M-rating and the four resource areas is shown in an example in Table 1. Anti-Air Warfare (AAW) has an M-rating of three due to

equipment and Anti-Surface Warfare (ASU) has an M-rating of two due to personnel.

PMA	RESOURCE AREAS				M-rating
	Per	Sup	Eqp	Tng	
AAW	2	2	3	1	M3
ASU	2	1	1	1	M2

Table 1. Relationship in SORTS between mission capability (M-rating) and the four resource areas for Primary Mission Areas AAW and ASU. From Ref. [2].

The *C-rating* applies to each resource area across all of the PMAs [Ref 2, Encl.(20):p. 1]. This rating indicates the combat readiness for each resource area. For each resource area the C-rating is one better than the highest number. If two PMAs share that highest value, then the C-rating cannot be increased to one better than the highest number. For example, in Table 2, equipment is rated at 3 in

PMA	RESOURCE AREAS	
	Sup	Eqp
AAW	2	3
ASU	1	1
CCC	3	1
C2W	2	2
INT	3	2
MOB	1	1
STW	2	2

Resource		
Area	C-3	C-2

Table 2. Relationship in SORTS between combat readiness (C-rating) and the Primary Mission Areas for two resources. From Ref. [2].

AAW only, so the equipment C-rating can be increased to C-2. Supplies are rated at a 3 in both Command, Control and Communication (CCC) and Interdiction (INT), so its rating cannot be increased.

The third rating, the overall C-rating, applies to the overall readiness of the unit in question. It is also reported as one better than the lowest C-rating if only one area has this lowest rating.

The emphasis of this thesis is improving the rating of the training resource area. The relationship between the three ratings and the contribution of training is shown in an example in Table 3.

PMA	RESOURCE AREAS				
	Per	Sup	Eqp	Tng	M-rating
AAW	2	2	3	1	M3
ASU	2	1	1	1	M2
CCC	1	3	1	3	M3
C2W	2	2	2	2	M2
INT	2	3	2	3	M3
MOB	1	1	1	1	M1
STW	2	2	2	1	M2

Resource		Overall		
Area	C-2	C-3	C-2	C-3

Table 3. Relationship in SORTS between M, C, and Overall C-rating. The M-rating is for the PMAs and the C-rating is for the Resource Areas. Fictional data used. From Ref. [2].

The training column rating, or the T-rating, comes from the Monthly Training Report. This report indicates the level of combat readiness for aviators in the squadron.

Combat readiness is measured by the squadron's completion of the training and readiness matrix. The CNAP/CNAL instruction states:

The objective of a training program is to enable a squadron to progressively attain, maintain and optimize the highest level of training feasible in preparation for the unit's anticipated employment. By implementing an effective training program, flight crew mission capability is achieved and the highest feasible level of training is maintained.

This instruction has been developed to give the squadron commanding officer the flexibility to develop a comprehensive training program. Training matrix achievement is the key to readiness. [Ref 2 Encl.(1):p. 1]

For the Monthly Training Report, the training officer determines which qualifications have expired for an individual and then adds up the PMA points listed in the training and readiness matrix associated with each warfare area. This total is subtracted from the 100 total points possible. If that aviator still has 75 or more points associated with that warfare area, then he is considered combat-ready. Any number below 75 is considered not combat-ready [Ref 3:p. 17]. This process is repeated for each of the seven warfare areas.

After determining the combat-ready status, the aviators are divided into crews. The most qualified pilots are placed with the most qualified ECMOs. This process is continued for all six crews. If one person in the four man crew is below 75 PMA points, then the whole crew is

considered not combat-ready for that warfare area. For each warfare area, the overall readiness percentage is determined by dividing the number of combat-ready crews by the total number of crews available.

For example suppose a squadron has two crews with pilots P1, P2 and ECMOs E1, ..., E6, whose Anti-Air Warfare (AAW) PMA points are as follows:

<u>CREW 1</u>	<u>CREW 2</u>
P1>75	P2>75
E1>75	E4>75
E2>75	E5>75
<b>E3&lt;75</b>	<b>E6&lt;75</b>

Then the aviators would be reorganized into new crews:

<u>CREW1</u>	<u>CREW 2</u>
P1>75	P2>75
E1>75	E4>75
E2>75	<b>E3&lt;75</b>
E5>75	<b>E6&lt;75</b>

and the squadron would have one combat-ready crew for an AAW readiness percentage of 50%.

A squadron's goal is to maintain at least 85% of the crews combat-ready in each of the seven warfare areas. This 85% level yields a PMA T-rating of T-1, and would result in a one in the training column for the SORTS report. Table 4 illustrates the breakpoints for the PMA T-rating inputs to SORTS.

For a six-crew squadron, being T-1 means keeping all six crews combat-ready in each of the seven areas.

PMA Percentage	T-Rating
85-100%	T-1
70-84%	T-2
55-69%	T-3
0-54%	T-4

Table 4. PMA T-rating breakpoints. From Ref. [2]

The goal of this thesis is to produce a model to maximize the number of aviators above 75 points in each of the seven PMAs. A greater number of combat-ready aviators improves combat readiness and may improve T-ratings.

#### **B. CURRENT SCHEDULING METHOD**

The current method of aircrew selection for training is based on the Training and Readiness Automated Matrix (TRAX) program. TRAX is a computer system that stores and calculates training and readiness data for a squadron. It keeps track of qualifications and Primary Mission Area totals for individuals [Ref 4:p. 1]. TRAX uses inputs from the squadron training officer and calculates the current readiness. TRAX monitors the qualifications status of aviators and projects when qualifications expire.

What TRAX does not do is inform the decision maker on who should fly what events, or which events are more



important than others. The current methodology takes an *ad hoc* approach to scheduling. The aviators going out of qualification the soonest on the most events get scheduling priority, limited to the resources available and flight time equity among the aviators. No current method exists for discerning which events are more valuable in terms of readiness. No current method exists for matching crew assignments with events in an objective way to maximize training in a given month.

### **C. MODELING APPROACH**

This thesis develops a mixed integer programming model as a scheduling aid for Prowler operations officers. The model is implemented using the General Algebraic Modeling System (GAMS) and solved using the Optimization Subroutine library (OSL) [Ref. 5].

The model is designed to be an aid for decision makers but not replace their decision making. The decision maker enters the number of sorties available for scheduling and the planning month. The aviator's currency data is input using a spreadsheet. The output is saved in a text file format that is easily readable by most spreadsheet packages. Using a simple macro, the user can import and format the results. These results can then be used to

generate pilot and crew pairings based on crew seniority, preferences and best judgement of the decision maker.

#### **D. RELATED MODELS**

The following describes the most closely related models to the EA-6B scheduling problem and differentiates tactical scheduling problems from commercial airline scheduling. Three papers address problems similar to the problem of scheduling Prowler training, while there is a large body of literature on commercial airline scheduling (which we only touch on).

##### **1. Van Brabant's Model**

Van Brabant's thesis [Ref. 6] developed a prototype flight scheduling model. This thesis demonstrated the potential for using a computerized method of assigning aviators to improve a squadron's combat readiness. This prototype was an integer programming model designed to maximize training and readiness for any Navy squadron.

His model assumed every airplane was single seat. For multi-seat aircraft, the pilot and his crew were considered one and were modeled as a single entity. This assumption was based on the crew continuity concept, where crews that routinely train together are more effective in combat.

This model approached each qualification as a single flight. Multiple qualifications could not be earned in a single flight.

Van Brabant's model was solved on a PC and produced results in five minutes.

## **2. Walker's Model**

Walker [Ref. 7] built a model for an F-14 squadron and was the basis for Van Brabant's thesis. His model scheduled aviators for events based on a pilot's current readiness level and the maximum number of flights allowed for the period. Walker assumed crew continuity between the pilot and Radar Intercept Officer and explicitly addressed flight time equity among pilots.

This model expressed one training event as a single flight and grouped pilots into one of four levels of readiness.

Walker's model proved too complex to be solved on a PC and required a mainframe computer to produce results.

## **3. Brown's Model**

Brown [Ref. 8] created a bicriteria mixed integer programming model for USMC aviation and command and control squadrons. This thesis assigned individuals to events and time periods over a 90 day planning horizon. The primary

objective of the model was meeting training event sequences, event repetition, and qualification requirements. A secondary objective was addressing the equity of opportunity and workload in the schedules produced.

Brown tested his model using data from a command and control squadron and implied that it could serve to schedule aviators in aviation squadrons. His model was formulated in GAMS and was solved on a PC in 10 minutes.

#### **4. Airline Scheduling**

Airline scheduling differs significantly from military scheduling. Tactical military aircraft are scheduled to take off and land from the same location. Airline schedules often route their crews through several intermediate destinations before returning to their home base. A common objective of airline scheduling is finding a minimum cost assignment of flight crews to a given flight schedule, subject to labor and governmental restrictions. One paper on airline scheduling is Barnhart, Hatay and Johnson [Ref. 9]. They address airline scheduling and deadhead selection.

## **E.    THESIS OUTLINE**

This thesis addresses the problem of monthly sortie scheduling for an EA-6B Prowler squadron. Chapter I introduces the monthly training and readiness requirements and how squadrons determine and report unit readiness. Chapter II illustrates the specific requirements for Prowler scheduling. Chapter III gives the mathematical formulation of the model. Chapter IV describes the computational trials and results of the schedules produced. Chapter V lists conclusions and recommendations, including insights into the problem. An excerpt from the CNAP/CNAL instruction is presented in the Appendix.



## II. PROWLER SCHEDULING SPECIFICS

The EA-6B is a four-person aircraft designed for carrier and advanced base operations. It is a modification of the two-seat Grumman A-6 airframe. A Prowler crew consists of one pilot occupying the front left seat, and three ECMOs.

ECMO One sits in the right front seat and is responsible for co-pilot duties, the navigation system, radios, communications system, radar, and the High Speed Anti-Radiation Missile (HARM) control panel. All but one of the training events can be done for full or half credit from the front seat. In completion of the training matrix, the front seat is the most important.

ECMOs Two and Three sit side by side in the back two seats. These seats are virtually identical and ECMOs in either back seat can fully employ the Prowler's weapons systems. The ECMOs in back operate the Electronic Surveillance Measures (ESM) system by listening for signals received through the tail mounted antennas. The Electronic Counter Measures (ECM) system is operated through the Digital Display Indicator located in front of the ECMO and consists of onboard computers and the ALQ-167 jamming pods mounted under the wings. The HARM missile can be targeted

from the back seat and this information is then passed up front for missile assignment.

A typical Prowler squadron consists of five aircraft, six pilots, and 18 ECMOs. Pilots and ECMOs have different currency requirements. ECMOs have specific seat requirements for their qualifications. This allows for over 29,000 possible crew assignments for a single flight and a much larger number of possible schedules.

#### **A. PROBLEM DEFINITION**

Monthly scheduling of aviators in a squadron consists of determining who needs to fly and what qualifications they need to earn. Qualifications can be combined to make up a single flight. Individual flights vary in the number and type of qualifications accomplished. Flights consisting of Field Carrier Landing Practice (FCLPs) may earn qualification in only one training area. Other flights may contribute ten qualifications or more.

Two constraints dictate what qualifications can be accomplished in one flight. First, a flight must be a logical progression of activities. For example, a single flight cannot consist of a daytime-only qual, followed by a nighttime-only qual, then a daytime qual. Second, flights are limited to the resources available. Many of the



qualifications in the latter half of the training and readiness matrix require substantial outside resources and cannot be accomplished without external help. This external help comes from an aircraft carrier or an electronic warfare range.

Training events are combined to form a flight. Complicating this combination are the particular requirements for the qualifications. These requirements differ between pilots and ECMOs.

Some qualifications are particularly demanding of a pilot's skill. These qualifications include acrobatics and formation flights. As such, their currency periods are shorter than for ECMOs.

Credit for ECMO qualifications is based on which seat the ECMO occupies. Approximately half (22 of 45) of the qualifications can only be earned by the ECMO occupying the right front seat. About one quarter of the qualifications (12 of 45) must be flown once in front and then once in the back seat before the qualification is earned. One qualification can only be earned from the back seat. The remaining qualifications can be accomplished by an ECMO occupying any seat in the airplane. Since the pilot can occupy only one seat in the airplane, a pilot earns

currency credit for any qualification accomplished in the airplane.

## **B. PRIMARY MISSION AREAS**

All training prescribed in the CNAP/CNAL instruction is divided into these seven Primary mission Areas (PMAs):

AAW - Anti-Air Warfare

ASU - Anti-Surface Warfare

CCC - Command, Control and Communication

C2W - Command and Control Warfare

INT - Intelligence

MOB - Mobility

STW - Strike Warfare. [Ref 3:p. 6]

For each of the seven PMAs, the CNAP/CNAL instruction specifies the qualifications and associated point values for accomplishing that qualification. Forty-five qualifications make up the training matrix. Each PMA warfare area has a total of 100 points associated with it. These 100 points are distributed across the qualifications, with points weighted with those tasks that contribute to training in that warfare area. Point values range from zero for a qualification that contributes nothing for that PMA to 20 for the most difficult task. Most qualifications contribute between two to six points for their warfare area. Table 5 shows three qualifications and the point

values contributed to each of the seven Primary Mission Areas.

QUAL/PMA	AAW	ASU	C2W	CCC	INT	MOB	STW
FAM1							
NATOPS	0	0	0	0	0	5	0
WAG1							
HARM	15	5	0	0	0	0	6
EWA1							
ESM	5	10	5	7	15	0	4

Table 5. Three training events (qualifications) and their associated Primary Mission Areas point values. From Ref. [3].

Once a qualification is successfully flown, the aviator is considered to be qualified and is awarded the appropriate PMA points. For the duration that an aviator remains qualified, re-flying a qualification does not earn any more points. Maintaining qualification keeps the aviator from losing the points he has already earned. By flying a qualification from an unqualified status, an aviator gains points towards the PMA goal of 100 total points. If an aviator falls out of qualification, they lose the points in all warfare areas associated with that qualification. At the end of every month, the training officer determines which qualifications have expired for an individual and then adds up the PMA points associated with each warfare area. This total is subtracted from the 100 total points possible. If that aviator still has 75 or more points associated with that warfare area, then he is

considered combat-ready. Any number below 75 is considered not combat-ready [Ref 3:p. 17].

### **C. TRAINING AND READINESS MATRIX**

The EA-6B Squadron Training and Readiness Program [Ref. 3] (which is subordinate to the CNAP/CNAL instruction) describes the specifics of the training and readiness matrix.

The training and readiness matrix specifies 45 qualifications, and characterizes each qual by 10 descriptors that reference various aspects of that qualification. The APPENDIX is an excerpt from the Prowler specific training and readiness matrix [Ref. 3]. It shows the relationship between the qualifications and the 10 descriptors. These descriptors include:

#### **1. Training Event Number**

The first descriptor numbers the 45 qualifications and indicates which events can be done in a simulator for partial credit.

#### **2. Event Code**

The event code describes the events and breaks them down into seven categories:

- a. Familiarization (FAM) flights regulate basic airman-ship, emergencies, air refueling, section and division formations, and night flights.

- b. Navigation (NAV) flights consist of low-level terrain following tactics, radar navigation, and Automatic Carrier Landing System (ACLS) approaches.
- c. Weapons proficiency is regulated by Weapons Air to Ground (WAG) requirements for the High Speed Anti-Radiation Missile (HARM) and its related systems.
- d. Strike (STK) flights govern the tactics and employment of the active electronic warfare systems in air wing and joint missions.
- e. Air Combat Training (ACT) flights govern air combat training.
- f. Threat warning and counter targeting tactics are employed in the Air to Air Warfare (AAW) flights.
- g. Electronic Warfare and Attack (EWA) flights consist of Electronic Surveillance Measures (ESM), active jamming against Integrated Air Defense Systems and communications jamming.

### **3. Initial Qualification for Pilot/ECMO**

This is what must be accomplished on a given flight for that aviator to be considered qualified. In all but three cases, an initial qualification can be earned with one flight.

### **4. Maintain Qualification for Pilot/ECMO**

This is what must be accomplished on a given flight to maintain currency. All maintain qualification events can be earned with one flight.

### **5. Currency Period**

The currency period states how many days an aviator remains qualified. At the end of each month, the training

officer submits the Monthly Training Report stating the readiness status. This means currency can be modeled on a monthly basis using the last day of the month as the day all qualifications are earned.

The currency requirements for pilots are stricter than for ECMOs. In eight qualifications, pilot currency is half the duration of ECMO currency. These qualifications are the most demanding of a pilot's skill. This is due to the close proximity of other aircraft, the proximity of the ground, or flight in unusual attitudes.

#### **6. Primary Mission Area Points**

Each PMA has a total of 100 points associated with it. This descriptor spans seven columns in the guidance instruction, one for each PMA. Each column states how many PMA points are associated with a qualification.

#### **7. Event Hours**

This column gives the estimated amount of flight time required to complete each qualification.

#### **8. Annual Hours**

This column shows the estimated annual flight hours required to remain current using event hours and currency.

## **9. Ordnance**

Prowlers carry chaff and flares, the CATM-88, and the AGM-88 HARM missile. Ordnance required for specific events is listed here.

## **10. Resources Required**

This column lists the external resources required to complete a qualification. This ranges from an emitter sending out signals to receive and jam, to low level route authorization.

### **D. NATOPS QUALIFICATIONS**

The Naval Air Training and Operating Procedures Standardization (NATOPS) flights are annual evaluations of procedures and aviator knowledge of aircraft systems.

A Prowler squadron designates two pilots and two ECMOs within the squadron to act as NATOPS instructors. These instructors evaluate the rest of the squadron members' compliance with the NATOPS program. As such, these aviators do not receive currency credit for evaluating other aviators. However, they do earn currency credit for all other qualifications accomplished in the airplane. For ECMO instructors, credit is given based on the seat the instructor occupies during the flight.

#### **E. FOLLOW-ON QUALIFICATIONS**

Some qualifications must be accomplished in a certain order. Some qualifications require currency in a related, easier task before moving on to a more difficult qualification. The pilot and front seat ECMO must be current in the prerequisite qualification before the follow-on qualification can be flown. If they are not current, then they must fly the prerequisite qualification before scheduling the follow-on. Successfully accomplishing a follow-on qualification updates currency for prerequisites leading up to that qualification. Seventeen qualifications are listed as prerequisites. Ten qualifications require prerequisite currency.



### III. MATHEMATICAL MODEL

The EA-6B Monthly Sortie Planning Model determines the optimal assignment of aircrew and events to flights. It is designed to be used as a scheduling aid for squadron operations officers. The objective of the model is to maximize overall squadron readiness subject to the initial readiness state and the number of flights available. The problem is formulated as a mixed integer program where aircrew are scheduled for events over a time horizon of one month.

#### A. INDICES

e	ECMOs in squadron (E1, ..., E18);
f	Flights pilots and ECMOs can fly;
m	Primary Mission Areas, (AAW, ..., STW);
p	Pilots in squadron (P1, ..., P6);
q	Qualification events that pilots and ECMOs must complete (F1, ..., EW3);
s	Seat ECMO occupies, (FR, BK).

#### B. DATA

##### 1. Given Data

AQ	Subset of quals (q) that an ECMO can accomplish from any seat;
BQ	Subset of quals (q) that an ECMO can accomplish only from the back seat;

FB	Subset of quals (q) that an ECMO must accomplish in both the front and back seat. Requires two flights;
FQ	Subset of quals (q) that an ECMO can accomplish only in the front seat;
Iq	Subset of quals (q) that require two flights to regain currency;
Maxflts	Maximum number of flights per month;
OK <sub>q</sub>	Subset of flights (f) that satisfy qual event (q);
PEN	Penalty for violating combat readiness (See 4 below);
Pf	Set of all prerequisite (q) and follow-on (q') qualification pairs;
pqm <sub>q,m</sub>	PMA points earned in qual event (q) towards Primary Mission Area(m);
Pr	Subset of quals (q) that are prerequisites for follow-on events;
termE <sub>q</sub>	Number of months qual event (q) is valid for each ECMO;
termP <sub>q</sub>	Number of months qual event (q) is valid for each pilot.

## 2. Derived Data

Qe <sub>e,q</sub>	1 if ECMO (e) is current in prerequisite qual (q: q ∈ Pr), otherwise 0;
Qp <sub>p,q</sub>	1 if pilot (p) is current in prerequisite qual (q: q ∈ Pr), otherwise 0.

## C. VARIABLES

### 1. Binary Variables

$UNQE_{e,q}$	1 if ECMO (e) goes out of qual (q) in the planning month;
$UNQP_{p,q}$	1 if pilot (p) goes out of qual (q) in the planning month;
$X_{p,f}$	1 if pilot (p) completes flight (f) for personal qual;
$Y_{e,f,s}$	1 if ECMO (e) completes flight (f) in seat (s).

### 2. Non-Negative Variables

$ANYP_f$	Generic pilot that flies flight (f) for ECMO-only quals;
$CE_{e,m}$	Elastic variable, the number of points below combat readiness (75% PMA) for ECMO (e) in PMA (m);
$CP_{p,m}$	Elastic variable, the number of points below combat readiness (75% PMA) for pilot (p) in PMA (m);
$NIE_f$	Any NATOPS Instructor ECMO for pilot NATOPS check flight (f);
$NIP_f$	Any NATOPS Instructor pilot for ECMO NATOPS check flight (f).

#### D. Formulation

OBJECTIVE FUNCTION

MINIMIZE:

$$\begin{aligned} & \sum_p \sum_{q: \text{ q expired or expiring}} \sum_m \text{UNQP}_{p,q} * \text{pqm}_{q,m} * \text{termP}_q + \\ & \sum_c \sum_{q: \text{ q expired or expiring}} \sum_m \text{UNQE}_{c,q} * \text{pqm}_{q,m} * \text{termE}_q + \\ & \text{PEN} * \sum_p \sum_m \text{CP}_{p,m} + \text{PEN} * \sum_c \sum_m \text{CE}_{c,m} \end{aligned} \quad (1)$$

SUBJECT TO:

$$\sum_{\substack{f: \\ f \in \text{OK}_q}} X_{p,f} \geq 1 - \text{UNQP}_{p,q} \quad (2)$$

$\forall p, \forall q: q \text{ expired or expiring in current month}$

$$\sum_{\substack{f: \\ f \in \text{OK}_q}} Y_{e,f,'FR'} \geq 1 - \text{UNQE}_{e,q} \quad (3a)$$

$\forall e, \forall q \in \text{FQ}: q \text{ expired or expiring}$

$$\sum_{\substack{f: \\ f \in \text{OK}_q}} Y_{e,f,'BK'} \geq 1 - \text{UNQE}_{e,q} \quad (3b)$$

$\forall e, \forall q \in \text{BQ}: q \text{ expired or expiring}$

$$\sum_{\substack{f: \\ f \in \text{OK}_q}} \sum_s Y_{e,f,s} \geq 1 - \text{UNQE}_{e,q} \quad (3c)$$

$\forall e, \forall q \in \text{AQ}: q \text{ expired or expiring}$

$$\sum_{\substack{f: \\ f \in \text{OK}_q}} Y_{e,f,s} \geq 1 - \text{UNQE}_{e,q} \quad (3d)$$

$\forall e, \forall q \in \text{FB}, \forall s: q \text{ expired or expiring}$

$$100 - \sum_q \text{UNQP}_{p,q} * \text{pqm}_{q,m} + \text{CP}_{p,m} \geq 75 \quad (4a)$$

$$\forall p, \forall m$$

$$100 - \sum_q \text{UNQE}_{e,q} * \text{pqm}_{q,m} + \text{CE}_{e,m} \geq 75 \quad (4b)$$

$$\forall e, \forall m$$

$$\text{ANYP}_f + \text{NIP}_f + \sum_p \text{X}_{p,f} = \sum_e \text{Y}_{e,f,'FR'} + \text{NIE}_f \quad (5a)$$

$\forall f$ : NIP and NIE only for NATOPS flights

$$2 * \left[ \text{ANYP}_f + \text{NIP}_f + \sum_p \text{X}_{p,f} \right] \geq \sum_e \text{Y}_{e,f,'BK'} \quad (5b)$$

$\forall f$ : NIP for NATOPS flights only

$$\sum_s \text{Y}_{e,f,s} \leq \sum_p \text{X}_{p,f} + \text{ANYP}_f + \text{NIP}_f \quad (5c)$$

$\forall e, \forall f$ : NIP for NATOPS flights only

$$\sum_{\substack{p: \\ \text{NATOPS qual due}}} \text{X}_{p,f} = \sum_{\substack{e: \\ \text{NATOPS Inst ECMO}}} \text{Y}_{e,f,'FR'} + \text{NIE}_f \quad (6a)$$

$\forall f$ : NATOPS flight

$$\sum_{\substack{e: \\ \text{NATOPS qual due}}} \text{Y}_{e,f,'FR'} = \sum_{\substack{p: \\ \text{NATOPS Inst Pilot}}} \text{X}_{p,f} + \text{NIP}_f \quad (6b)$$

$\forall f$ : NATOPS flight

$$\sum_p \text{X}_{p, \text{LEAD}} + \text{ANYP}_{\text{LEAD}} = \sum_p \text{X}_{p, \text{WING}} + \text{ANYP}_{\text{WING}} \quad (7a)$$

$\forall f$ : section flights, (Lead, Wing)

$$2 * \left[ \sum_s Y_{e, \text{LEAD}, s} + \sum_s Y_{e, \text{WING}, s} \right] \leq \sum_p X_{p, \text{LEAD}} + \sum_p X_{p, \text{WING}} \quad (7b)$$

$\forall e$

$$\sum_{\substack{f: \\ f \in \text{OK}_{q'}}} X_{p, f} \leq |\text{OK}_q| * \left[ \sum_{\substack{f: \\ f \in \text{OK}_q}} X_{p, f} \right] \quad (8a)$$

$\forall p \text{ and } (q, q') \in Pf \mid Qp_{p, q} = 0$

$$\sum_{\substack{f: \\ f \in \text{OK}_q}} Y_{e, f, 'FR'} \leq |\text{OK}_q| * \left[ \sum_{\substack{f: \\ f \in \text{OK}_q}} Y_{e, f, 'FR'} \right] \quad (8b)$$

$\forall e \text{ and } (q, q') \in Pf \mid Qe_{e, q} = 0$

$$\sum_{\substack{f: \\ f \in \text{OK}_q}} X_{p, f} + 2 * \text{UNQP}_{p, q} \geq 2 \quad (9a)$$

$$\forall p, \forall q \in Iq: \quad q \text{ expired}$$

$$\sum_{\substack{f: \\ f \in \text{OK}_q}} Y_{e, f, 'FR'} + 2 * \text{UNQE}_{e, q} \geq 2 \quad (9b)$$

$$\forall e, \forall q \in Iq: \quad q \text{ expired}$$

$$\sum_p \sum_f X_{p, f} + \sum_{\substack{f: \\ \text{NOT NATOPS}}} \text{ANYP}_f + \sum_{\substack{f: \\ \text{NATOPS}}} \text{NIP}_f \leq \text{Maxflts} \quad (10)$$

## **E. DISCUSSION**

### **1. Objective Function**

The purpose of the model is to maximize the number of combat-ready aviators. This is accomplished by minimizing the loss of currency for pilots and ECMOs plus the sum of penalties for losing combat readiness. PMA points alone are not sufficient to determine which events have the greatest value. An event contributing 2 points for one month is not as valuable an event contributing 2 points for each of 12 months. Therefore, the value placed on currency in each qualification is PMA points times the length of currency for that qualification.

An elastic variable in the objective function adds a large penalty of 580 if an aviator is below 75% in a PMA. (See (4) below.)

### **2. Pilot Currency**

This constraint identifies the qualifications in which each pilot has lapsed or lapses at the end of the month, and specifies that the pilot be requalified or a penalty is assessed.

### **3. ECMO Currency**

These constraints identify the qualifications in which each ECMO has lapsed or lapses at the end of the month, and

specifies that the ECMO be requalified or a penalty is assessed.

ECMO qualifications can be earned either in the front seat(3a), only the back seat (3b), either seat (3c), or once in the front and once in the back (3d).

#### **4. Combat Readiness**

The elastic constraints (equations (4a) and (4b)) represent the number of points below 75 that an aviator has lost towards combat readiness. Violation of these constraints carries a penalty of 580 in the objective function. This penalty is greater than 576, which is the largest single qualification product of PMA points and currency. Combat readiness is defined at 75 PMA points. No added benefit is gained for earning greater than 75 points. It is better to have all aviators at 75 points than to have most at 100 points and one aviator below 75 points. Each point below 75 is penalized.

#### **5. Proper Crews**

Constraints (5a) through (5c) ensure the proper mix of pilots and ECMOs in the airplane. Constraint (5a) requires that each flight have a pilot paired with an ECMO in the front seat. Constraint (5b) limits the number of ECMOs in the back seats to two or less. Constraint (5c) ensures



that ECMOs are not simultaneously scheduled in the front and the back in the same airplane.

## **6. NATOPS Flights**

The NATOPS constraints, (6a) and (6b), pair up NATOPS instructors with the aviators they are evaluating. Pilot instructors evaluate ECMOs, and ECMO instructors evaluate pilots. This is necessary because the instructor cannot get currency credit for the NATOPS qualification, but can get currency credit for all other events accomplished in that flight.

## **7. Section Flights**

Section qualifications involve two aircraft flying the same flight. One airplane is designated the lead and the other aircraft is designated wing. Constraint (7a) dictates that two airplanes must be scheduled to maintain currency in a section proficiency qualification. This constraint is repeated for each pair of flights with section qualifications, one variable representing the lead and the other variable for the wing. For example, flight 40 and flight 41 are a section flight pair and both earn the same qualifications. The aircrew flying flight 40 would be designated lead and the aircrew flying flight 41 would be designated wing. Therefore the index labeled

"lead" would be written as "FL40" (flight 40) and the index labeled "wing" would be written as "FL41" (flight 41).

This is repeated for each lead/wing flight combination. In the real data used in this thesis, there were relatively few of these combinations. Constraint (7b) limits an ECMO from flying in both the lead and wing aircraft in the same section flight. As written, this constraint does not allow an ECMO to be scheduled with any pilot (variable  $ANYP_f$ ) for a section flight. This may not always be true, but section flights are typically scheduled primarily for specific pilot currency.

#### **8. Prerequisite Flights**

The prerequisite constraints, (8a) and (8b), govern the scheduling of follow-on flights. The pilot and front seat ECMO must either be current or scheduled for all prerequisites before the follow-on qualification can be earned.

#### **9. Initial Qualification Flights**

Three qualifications require two flights to regain currency from an unqualified status. Fam 5, Nav 1 and Nav 2 all require the aviator to successfully complete these qualifications twice in order to regain currency. Constraint (9a) governs the initial qualification for

pilots and constraint (9b) governs the initial qualification for ECMOs.

#### **10. Maximum Flights Available**

The total number of flights scheduled must be no more than the number available. Since each Prowler crew has exactly one pilot, the number of pilots scheduled accurately depicts the number of flights.



#### IV. COMPUTATIONAL TRIALS

This scheduling model is implemented in GAMS [Ref 6.], solved with OSL on a PC with a Pentium/120MHz processor, and tested using data from one operational squadron over three different months. The model contains 2,500 variables and typically solves in 10 minutes with a relative optimality tolerance ( $[MIP - LP] / LP$ ) of 5% for the mixed integer program. This chapter presents a description of the test data used and a comparison of actual readiness versus the readiness that would be obtained from the model.

##### A. DATA

The focus of the model is to help the decision maker schedule aircrew and events to maximize training. In order to make an accurate comparison, the model's results have to be compared with what a squadron actually did accomplish. A Prowler squadron based at Naval Air Station, Whidbey Island, WA, aided this thesis in supplying the monthly readiness data for each aircrew in the seven warfare areas. The data received was sanitized to keep the information unclassified. The names of the aviators were changed to P1, ..., P6 and E1, ..., E18. This squadron also supplied the training debrief forms, with each form annotating the

training events accomplished by aircrew during a single flight.

From these forms, an input file was created using the actual flights flown and the training events accomplished on those flights. This forced the model to schedule the same flights for the modeling month as those actually flown by the squadron.

Another input file, created using a spreadsheet, listed the aviators and their currency in each of the qualifications. By using this information as an input, the model determined which aviators were lapsing in currency. These aviators were then scheduled using the list of flights available.

The readiness percentage was calculated for the beginning and end of the month. By comparing the actual readiness percentage achieved by the squadron to the model's output, the improved readiness using the same resources can be shown.

#### **B. SCHEDULES PRODUCED**

The monthly schedule produced by the model is a matrix assigning aviators to the available flights. The output is a text file which can be read by most spreadsheet packages. Table 6 shows a sample schedule that the user would see,

using the spreadsheet format of the pilot to flight scheduling matrix. The anypilot (ANYP) column lists those flights that are flown only for ECMO currency. These flights can be assigned to any pilot and enable the decision maker to maintain flight hour equity among the pilots. The NATOPS instructor pilot (NIP) column indicates that the flight is only scheduled for ECMO currency but must be flown by a NATOPS instructor pilot.

	P1	P2	P3	ANYP	NIP
FLT10	1	1	0	0	0
FLT11	0	0	1	1	0
FLT12	0	0	0	0	0
FLT14	0	0	0	0	1
FLT40	0	1	0	0	0
FLT41	1	0	0	0	0

Table 6. Sample pilot schedule utilizing 7 flights. The number 1 indicates that a specific pilot, anypilot (ANYP) or NATOPS Instructor Pilot (NIP) is assigned to that flight.

Table 7 shows a sample schedule using the spreadsheet format of the ECMO to flight matrix. This output lists the flights to be scheduled, the aviators assigned to those flights, and the seat the aviator is to occupy during that flight.

The model output assigns aviators to flights, but does not match up crews within those flights. This is done intentionally to allow the decision maker to generate crew

assignments. These crew assignments are based on squadron Standard Operating Procedures, crew seniority, crew continuity and the decision maker's judgment.

		E1	E2	E3	E4	NIE
FLT10	FR	0	0	1	0	1
	BK	1	1	0	1	0
FLT11	FR	1	1	0	0	0
	BK	0	0	1	0	0
FLT12	FR	0	0	0	0	0
	BK	0	0	0	0	0
FLT14	FR	0	0	0	1	0
	BK	1	1	0	0	0
FLT40	FR	0	0	1	0	0
	BK	1	0	0	0	0
FLT41	FR	0	1	0	0	0
	BK	0	0	0	0	0

Table 7. Sample ECMO schedule utilizing 7 flights. The number 1 indicates that a specific ECMO, or NATOPS instructor ECMO (NIE) is assigned to that flight in either the front (FR) or back (BK) seat.

The output does not fill the back seats on every flight. If no lapsing qualifications can be earned on that flight, then the back seats are left open. These open seats can be utilized to obtain the proper mix of aviators within the flight. Obtaining a proper mix require including a Mission Commander or pairing an inexperienced aviator with a veteran. Leaving open seats in the back also gives the decision maker the flexibility to maintain flight hour equity among the ECMOs.



## C. RESULTS SUMMARY

The model was tested using the flights actually flown by the squadron during the months of September, November, and January. The initial readiness state was determined, followed by the readiness achieved by the squadron at the end of the month.

### 1. September

For the month of September, the squadron flew a total of 56 flights. Of those 56 flights, 26 were discretionary flights and 20 were repeat qualifications of Field Carrier Landing Practice (FCLP) in preparation for an upcoming carrier detachment.

Figure 1 illustrates the inadequacy of the *ad hoc* approach to scheduling. After one month of training, the squadron actually **lowered** its overall average readiness. This was due to earning qualifications that were not expiring and not earning the right mix of qualifications that were due to expire. By contrast, the model utilized the same types of flights that earned the same qualifications, but chose different crews to occupy the aircraft. Using the same number of flights, an average combat readiness of 74.7% was achieved. This overall average readiness indicates the squadron as a whole would

have been just shy of the 75% goal for full combat readiness.

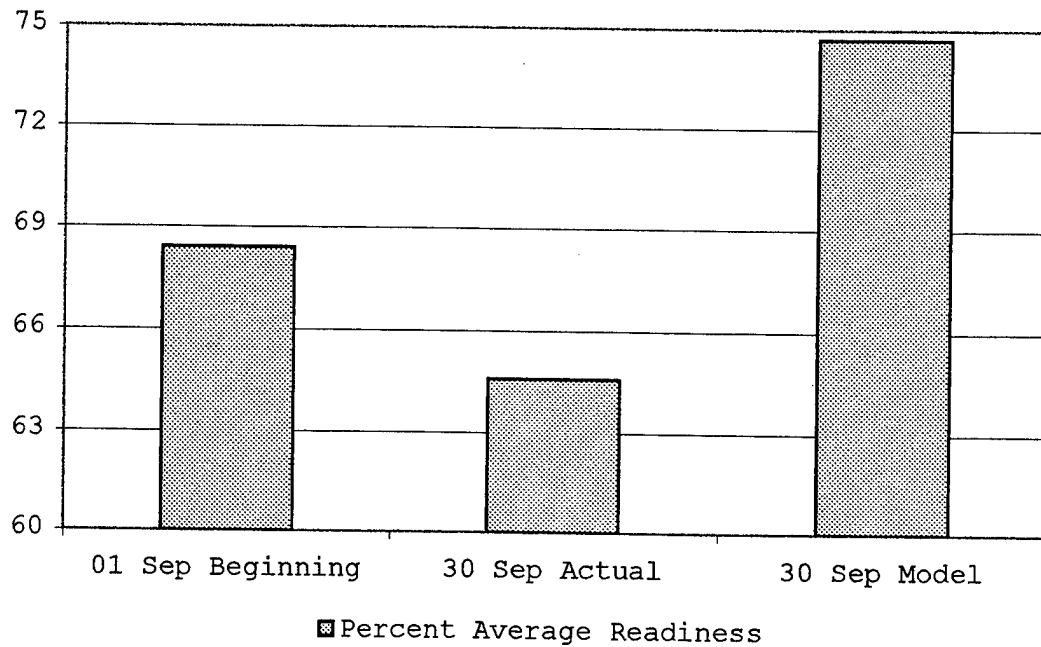


Figure 1. September Percent Average Readiness  
Across All PMAs Utilizing 26 Flights

In practice, the readiness state of the squadron is not reported as overall average percent readiness, but as a T-rating. In determining the T-rating, the training officer looks at each Primary Mission Area and starts assigning aviators to crews of four to maximize the number of combat-ready crews. The most qualified pilots are paired with the three most qualified ECMOs. By dividing the number of combat-ready crews by the number of crews on board, a percentage is obtained. This percentage is used

in Table 2 to determine the T-rating. By arranging crews this way, the combat readiness of the squadron is determined for each of the seven PMAs. Figure 2 illustrates the T-rating improvement over five of the seven PMAs.

The mobility and strike warfare PMAs remained at their lowest rating, due to two factors: flights including Fam

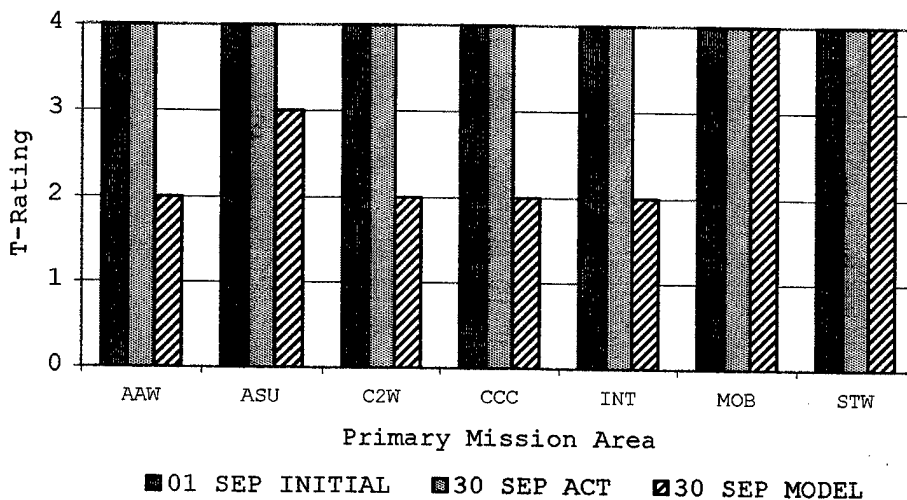


Figure 2. September T-Rating Across All PMAs  
Comparing Actual Readiness Achieved to Model  
Output

\*Lower T-Ratings Are Preferred

12, and flights involving strike warfare qualifications were not flown by the squadron in September, and therefore were not available to be scheduled by the model. Fam 12 is the carrier qualification requirement and it requires an aircraft carrier. This lapse in qualification loses 20 of

the 25 points an aviator can lapse in before becoming not combat-ready.

## **2. November**

A second month was also analyzed to show that the September results were not unique. The month of November was used due to the unavailability of October data. This data could not be retrieved since TRAX overwrites currency qualifications rather than storing it.

In the month of November, the squadron was prepared for and detached on an aircraft carrier. The majority of their flight hours were utilized preparing for this evolution, and this involved flying and re-flying several qualifications for proficiency other than that reported in the Monthly Training report. Nine flights were flown that were not repeat qualifications in Field Carrier Landing Practice or Carrier Qualification.

Readiness achieved from the nine actual flights was compared to the readiness the model could have achieved, illustrated in Figure 3. Due to TRAX overwriting some of the November data, the T-ratings could not be reproduced.

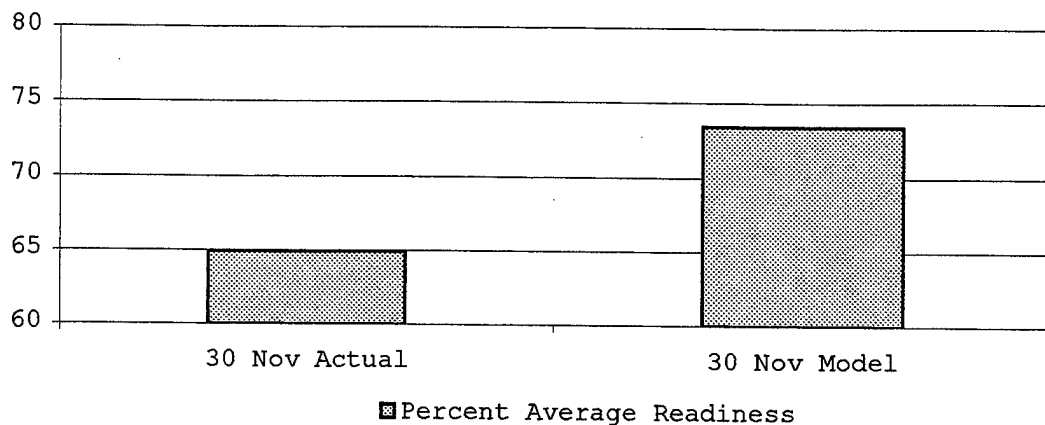


Figure 3. November Percent Average Readiness Across All PMAs Utilizing 9 Flights

### 3. January

In January, the squadron detached to NAS Fallon, NV, and was able to earn several qualifications not available from their home base. Even with this extra capability, the squadron still **lowered** its actual overall average readiness from December. Readiness for January dropped 2% to 64%. In contrast, the model achieved a 25% increase in readiness for January, up from 64% to 80% overall average readiness. Once again, the *ad hoc* method was inadequate in scheduling aviators to improve combat readiness. Figure 4 illustrates the contrast between the current scheduling method and the model.

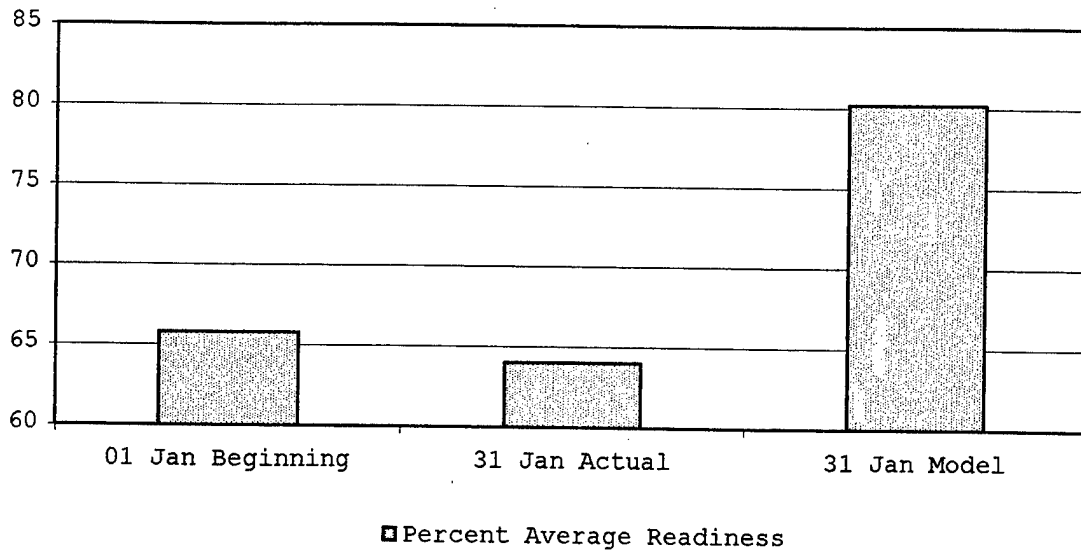


Figure 4. January Percent Average Readiness Across All PMAs Utilizing 32 Flights

For the September data, the model was compared to the actual readiness and a T-rating was calculated. Figure 2 illustrated the actual September T-ratings reported for each PMA. Figure 5 also illustrates the T-rating improvement using the model in January.

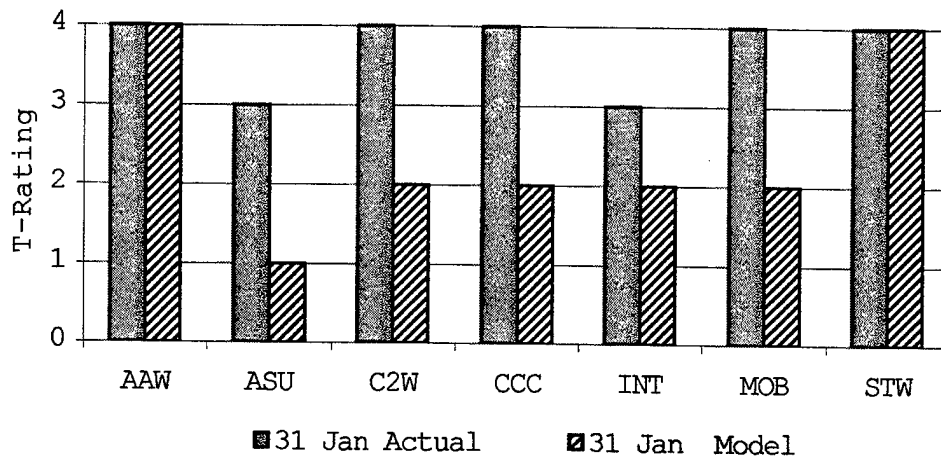


Figure 5. January T-Rating Across All PMAs  
Comparing Actual Readiness to Model Readiness

\*Lower T-Ratings Are Preferred

#### D. CUMULATIVE READINESS

The EA-6B Monthly Sortie Planning Model enables a squadron to achieve a 10% increase in readiness in a single month. A squadron that implemented this model would also have a cumulative increased readiness, where the previous month would contribute to a higher state of readiness for the following months. Figure 6 illustrates this cumulative effect. The squadron started at its initial readiness state on 01 September. Using the same flights actually flown, the model was solved for September. The readiness state was updated and the model solved for October using the same number and types of flights flown previously. The readiness was updated and a new list of flights was generated using the actual November flights.

The squadron had a carrier detachment in November and was able to fly only nine flights. With only nine flights available, the squadron expected to drop in readiness. The cumulative effect allowed the squadron to drop only 3% to 73.4% average overall readiness.

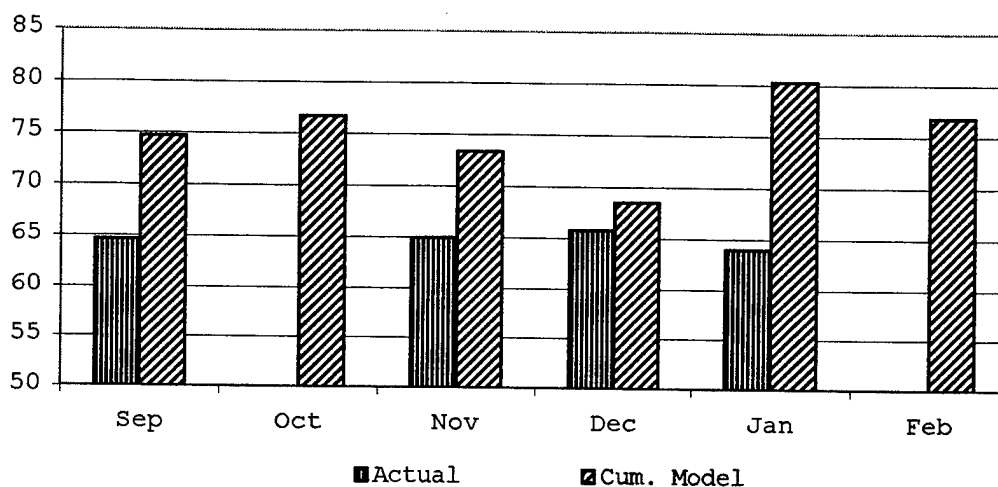


Figure 6. Monthly Percent Average Readiness. Comparison Between Actual Readiness and Cumulative Model Monthly Readiness  
 \*Data Unavailable for Oct and Feb

For December, the only data available was the overall average readiness at the end of the month. Due to the expected holiday leave period, the squadron flew a reduced number of sorties. The cumulative model was given the same number of flights to schedule as November. Even after two months of minimal flying, the model maintained an overall average readiness just below 69%.

Data for February was unavailable. The same number and types of flights flown in January was used for the



cumulative model. Even though this resulted in a small decrease in readiness due to the types of qualifications lapsing, the overall average readiness remained above 75%.

#### **E. FLIGHTS REQUIRED TO ACHIEVE 75%**

In order to complete the training and readiness matrix, Prowler crews operate and train at three primary locations. These locations are the aircraft carrier, NAS Fallon (in conjunction with the air wing and electronic warfare range), and the Prowler's home base at NAS Whidbey Island. With this variety in training environments and the external resources required, not all qualifications can be earned from one place or in one month.

If all resources were available and all qualifications could be earned in one month, the decision maker would be able to find an upper bound on the readiness capability of his squadron. Figure 7 illustrates the number of flights required to train each aviator to at least 75% in all PMAs. This is different than percent average readiness in that each aviator would be combat-ready and each PMA would have six combat-ready crews.

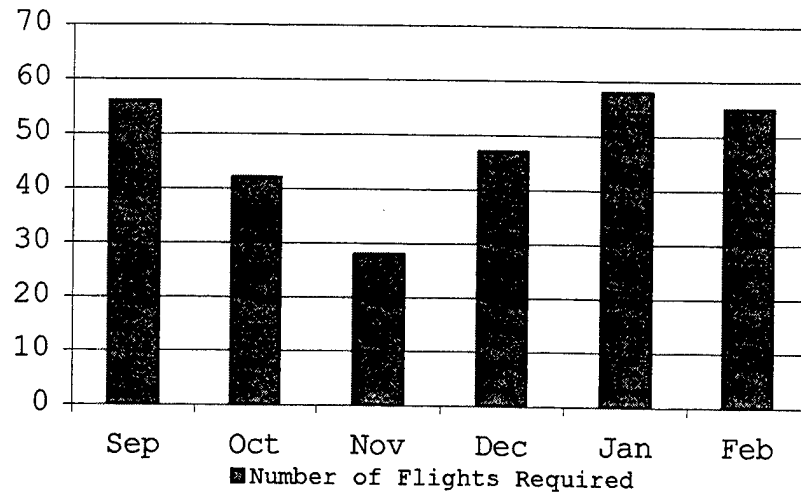


Figure 7. Number of Flights Required to Reach 75%  
in All PMAs for Each Aviator.  
\*Sub-Optimal Results After One Hour Solve

The flights used to create Figure 7 were based on the actual flights flown. Extra flights were created to enable the squadron to earn every qualification. This figure informs the decision maker as to how many more flights would have been required, and the extra external resources needed to achieve 75% in every PMA.

The ability to reach 75% in every PMA is dependent on the external resources available, and the external resources operate on their own schedule. If all qualifications were made available every month, then a yearly flight estimate could be made independent of the particular scheduling of these resources. This estimate could be used to determine how many flights were required on an annual basis to keep a squadron fully combat-ready.

Figure 8 indicates that 419 flights would be required to keep a squadron fully combat-ready in all PMAs.

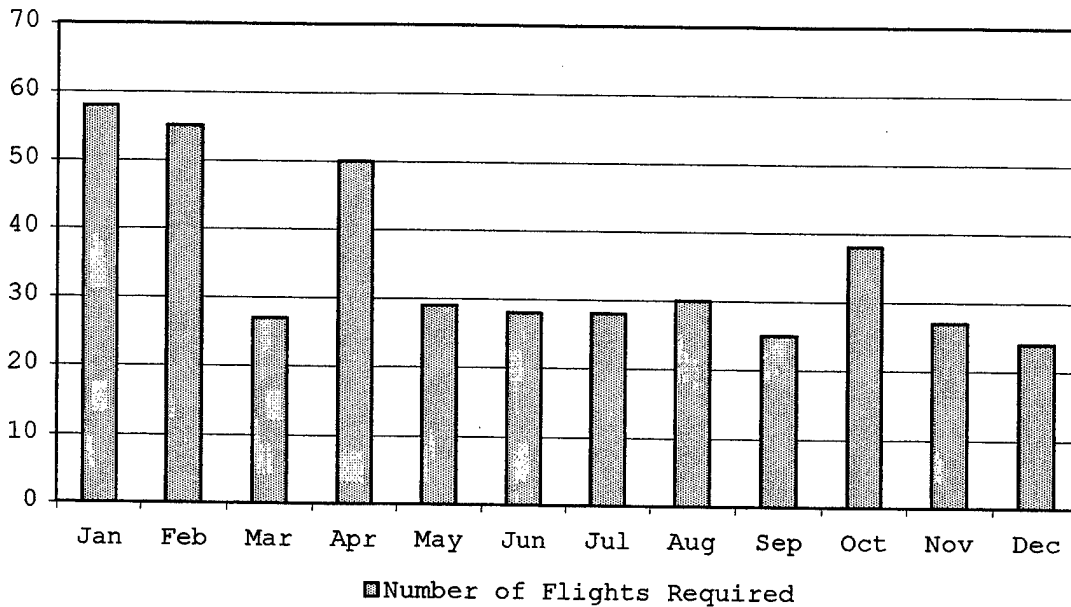


Figure 8. One Year Scenario of the Number of Flights Required to Reach 75% in All PMAs

During the initial months of the scenario, a large number of flights were required to reach 75%. Once this was achieved it became significantly easier to maintain 75%. This indicates that when a squadron has the funding and resources available, the sooner they achieve combat readiness, the easier it is to maintain that combat readiness.

The number of flights required to reach 75% in all PMAs proved to be a significantly more difficult problem to solve. The branch and bound search by the OSL solver often took hours to get solutions with a relative gap of 25%.

The model was stopped after one hour. These solutions, while not optimal, indicated an upper bound on how many flights would have been required to reach 75% in all PMAs.

## **V. CONCLUSIONS AND RECOMMENDATIONS**

The purpose of the flight scheduling model is to enable the decision maker to create a blue print for what his monthly sorties should accomplish. This allows him to decide what types of flights to schedule and which aviators to fly those missions.

### **A. MARGINAL FLIGHT VALUE**

The marginal value of a flight is useful to the decision maker for two reasons. First, it informs him on how much more readiness he can expect from one more flight. This is important because it allows the decision maker the ability to forecast his units' readiness, and gives him time to arrange extra funding or schedule external resources. Second, it shows him how much readiness he will lose by utilizing one less flight. This is important when pairing up flight crews with the model output. The decision maker may decide to deviate from the schedule in order to maintain crew continuity or to comply with squadron Standard Operating Procedures. The lost readiness due to these deviations can be determined using the marginal flight value.

Using the September readiness and flight data, Figure 9 was created.

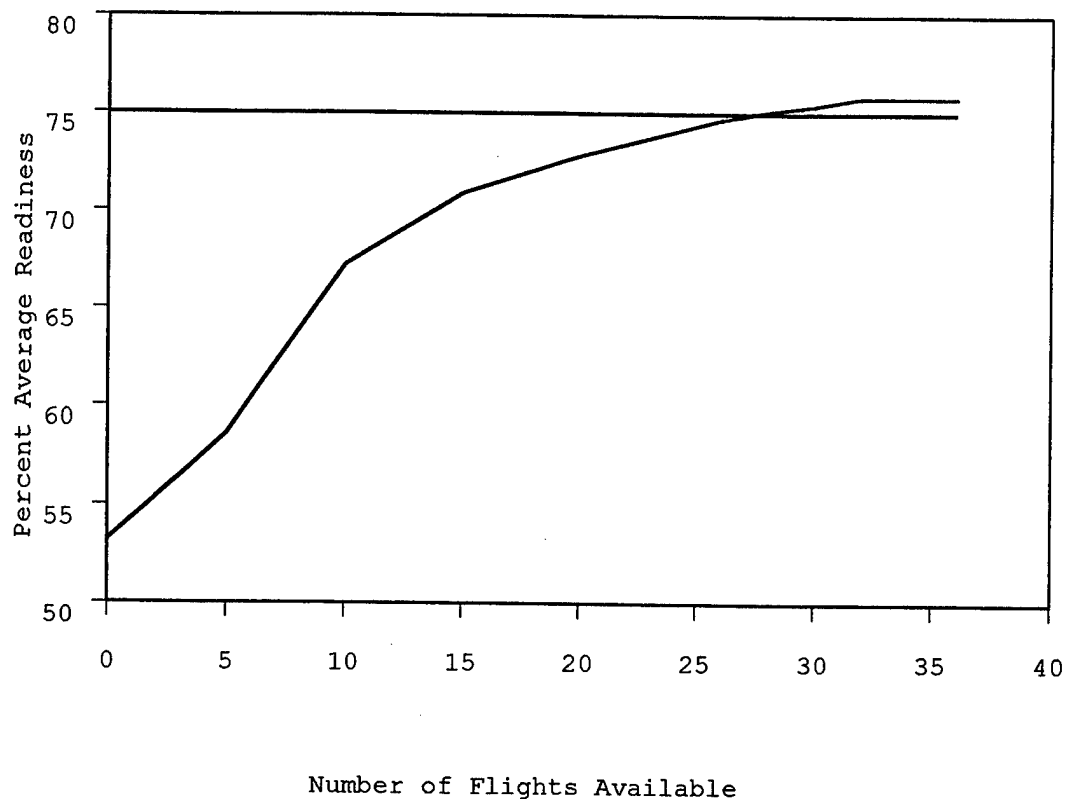


Figure 9. Marginal Flight Value Expressed as Overall Average Readiness with 75% Fully Combat-Ready Reference Line

The marginal value line was expected to appear concave, and this appears to be the case except where five flights were available. This is due to NATOPS flights that must be flown. These flights are not the most valuable in terms of readiness, but they must be completed to insure standardization. In the September analysis, three aviators required NATOPS flights. So three of the five available flights were used up before the model could allocate based on readiness.

The marginal value of flights at the upper end of the chart tapers off at 75.8%. This is due to the mix of available flights. Not all qualifications were capable of being flown (such as AC1, ..., AC3, and STK9,... STK11) so there is an upper bound on the level of readiness achievable in September.

#### **B. FURTHER RESEARCH**

The methodology presented in the model allows a decision maker the ability to generate a monthly sortie schedule. However, the decision maker is responsible for more than just sortie scheduling. An operations officer must also manage aircrew availability, flight funding, and monitor flight hours.

Further research needs to be conducted in the area of database management. A database is needed that can be used to interface with GAMS to produce the monthly big picture schedule, then be able to utilize these events and create the daily flight schedule.

#### **C. CONCLUSIONS**

The modeling approach gave an immediate 10% improvement in combat readiness over the current *ad hoc* method. This improvement in readiness results in a cumulative effect that allows a squadron to maintain their

squadron to maintain their proficiency even during months with minimal flight time. The methodology gives the decision maker an objective way of determining the value of a flight. The output enables the decision maker to plot out a course of monthly sorties and determine the effects of deviation from that course. It is recommended that the training and readiness model be implemented by Prowler squadrons to improve both their readiness and combat capability.



# EXCERPT FROM EA-6B TRAINING MATRIX

This excerpt illustrates the 10 descriptors for each qualification.  
After Ref. [3].

## APPENDIX

EA-6B TRAINING EVENT #	TRAINING EVENT CODE	INITIAL QUAL P/E	MAINTAIN QUAL P/E	CURR- ENCY PERIOD	AAW	ASU	C2W	OCC	INT	MOB	STW	EVT HRS	ANN HRS	NOTES	ORD- NANCE	RESOURCES REQUIRED
1 (F01/S01)	FAM1 NATOPS	1/1F	1/1F	Q+365						5 (5)		1.5 (2.0)	4.5			2F119/ 2F143
2 (F02/S02)	FAM2 INST CHK	1/1F	1/1F	Q+365						3 (3)		2.0 (2.0)	6.0			2F119/ 2F143
3 (F03/S03)	FAM3 AC/ST	1/1F	1/1F	(P)Q+60 (E)Q+90	6 (2)					5 (2)		0.5 (1.5)	9.1			2F119/ 2F143
4 (F04)	FAM4 DAY FRM	2/2F	1/1F	(P)Q+60 (E)Q+90		5				4	3	0.3	5.5			
5 (F05)	FAM5 TAC FRM	1/1F	1/1F	(P)Q+90 (E)Q+180	6					4	4	0.4	4.8			
6 (F06)	FAM6 NITE FRM	1/1F	1/1F	(P)Q+90 (E)Q+180		5				4	4	0.7	8.5			
7 (F07)	FAM7 DIV FRM	1/1F	1/1F	Q+180						3	3	0.8	1.6			
8 (F08)	FAM8 SECT AP	2/2F L&W	2/2F L&W	Q+120						3		0.8	14.6			
9 (F09)	FAM9 N SEC AP	2/2F L&W	2/2F L&W	Q+120						3		1	18.3			
10 (F10/S10)	FAM10 EMERG AP	2/2F NFNS&SE	2/2F NFNS&SE	Q+120						2 (2)		0.5 (0.5)	9.1	1		2F119/ 2F143
21 (F21/S21)	WAG1 HARM PR MODE	1/1F1B	1/1F1B	Q+30		15 (8)	5 (3)				6 (3)	0.2 (0.5)	7.3			2F119 15E22C/2 F119A
23 (F23)	WAG3 HARM SHOT	1/1A	1/1A	Q+2190		3	3				2	0.8	1		AGM- 88	TGT EMITTER
43 (F43/S43)	EWAL ESM RPT	1/1B	1/1B	Q+60	5 (3)	10 (5)	5 (5)	7 (3)	15 (8)		4 (2)	0.5 2.0	6			EW/15E34A



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